US006359743B1

(12) **United States Patent**
**Patti et al.**

(10) **Patent No.:** **US 6,359,743 B1**
(45) **Date of Patent:** ***Mar. 19, 2002**

(54) **APPARATUS AND METHOD FOR REDUCING THERMAL INTERFERENCE IN MR HEADS IN DISK DRIVES**


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(*) Notice: This patent issued on a continued prosecution application filed under 37 CFR 1.53(d), and is subject to the twenty year patent term provisions of 35 U.S.C. 154(a)(2).

Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.


(21) Appl. No.: **09/197,122**

(22) Filed: **Nov. 20, 1998**

(51) **Int. Cl.**[7] .................................................. **G11B 5/02**
(52) **U.S. Cl.** ............................. **360/25**; 360/65; 360/46
(58) **Field of Search** .............................. 360/25, 65, 46, 360/53, 67; 327/553, 559, 554, 555


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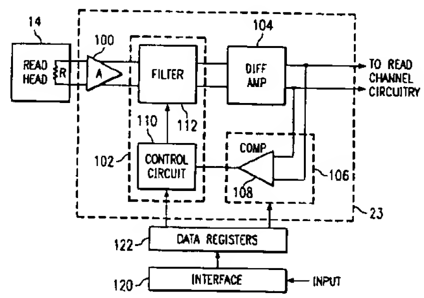
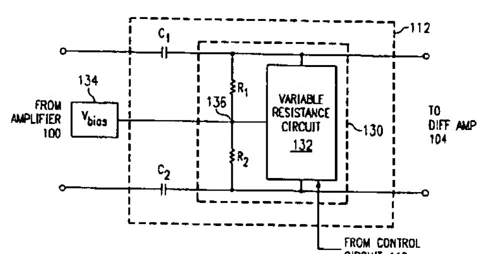
(57) **ABSTRACT**


An apparatus (and method) is provided that reduces thermal interference in the read signal of a disk drive. A variable or programmable resistance is used to change the transfer function of a filter in the read channel of the disk drive to filter the read signal. The filter has a first transfer function (first cut-off frequency) related to the programmed resistance during normal operation of the disk drive (i.e. when thermal interference is not detected). When thermal interference is detected in the read signal, the resistance is programmed to another value resulting in the filter having a second transfer function (second cut-off frequency). The resistance element is variable or programmable to different values resulting in different programmable transfer functions (or one of a multitude of cut-off frequencies) for the filter. In the preferred embodiment, detection of thermal interference increases the cut-off frequency of the filter thereby filtering, or reducing the effects of, the thermal interference in the read signal.


**39 Claims, 5 Drawing Sheets**



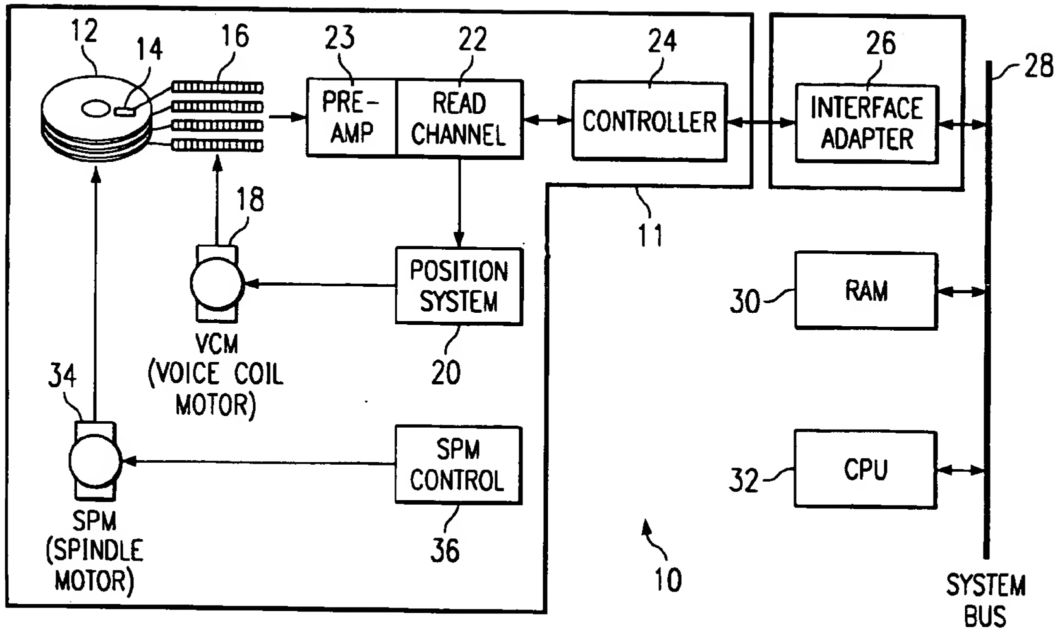



FIG. 1

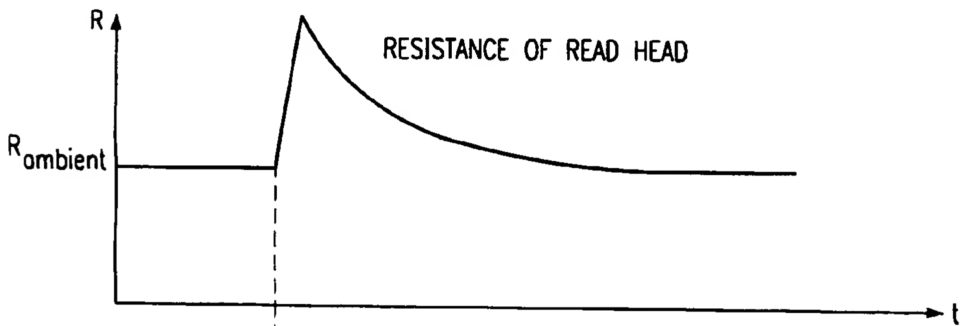



FIG. 2B

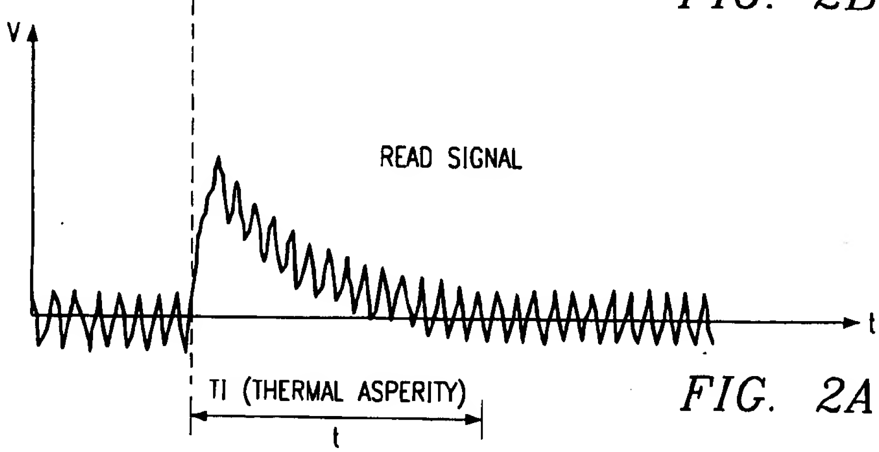



FIG. 2A

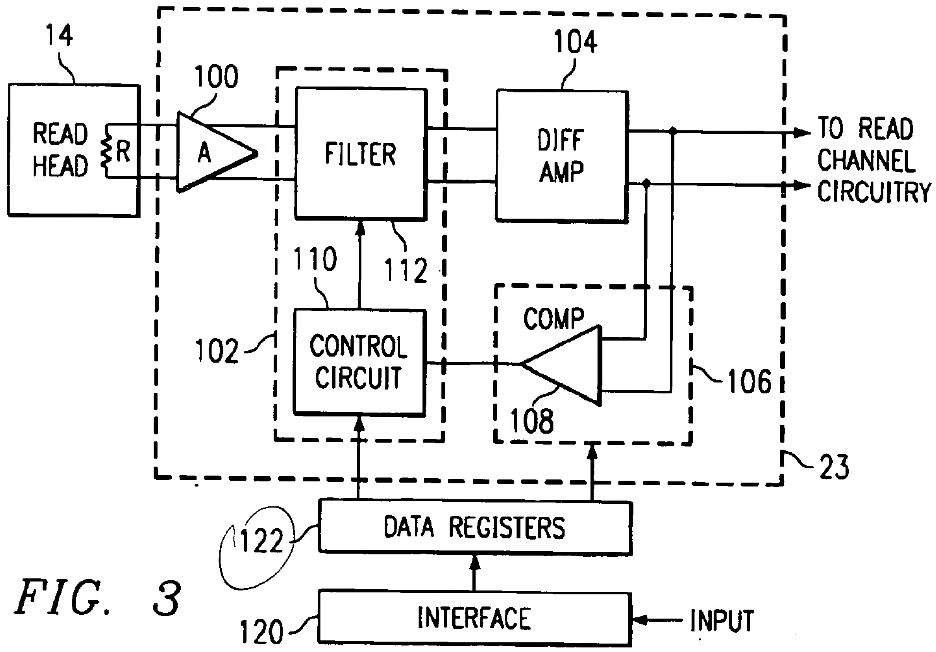

14
READ HEAD
R
100
A
FILTER
104
DIFF AMP
TO READ CHANNEL CIRCUITRY
110
112
102
CONTROL CIRCUIT
COMP
106
108
23
122
DATA REGISTERS
120
INTERFACE
INPUT

FIG. 3

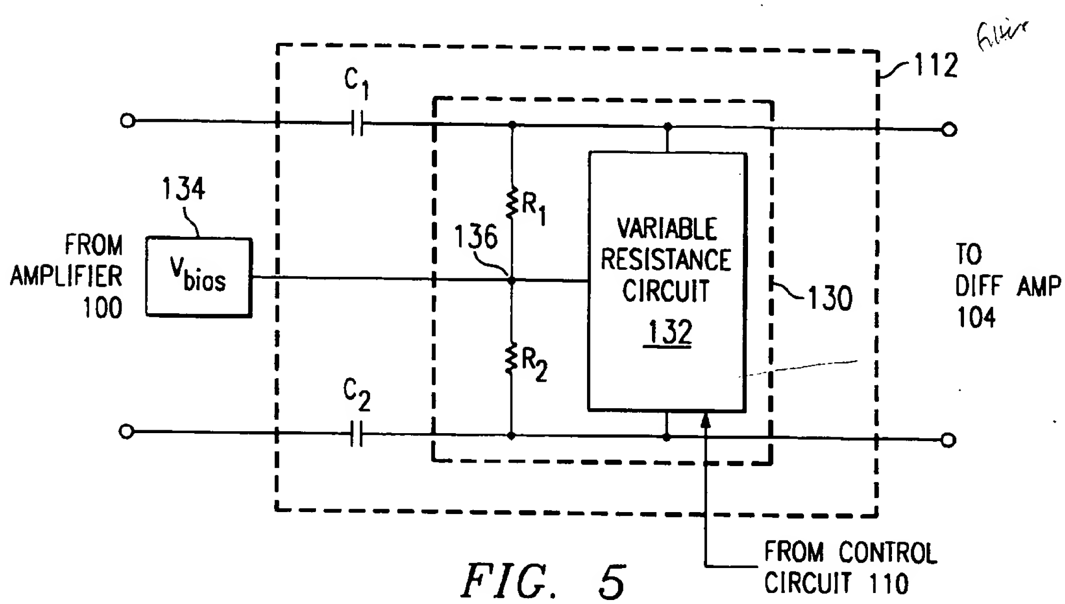

112
filter
$C_1$
134
FROM AMPLIFIER 100
$V_{bios}$
$R_1$
136
VARIABLE RESISTANCE CIRCUIT
132
130
TO DIFF AMP 104
$R_2$
$C_2$
FROM CONTROL CIRCUIT 110

FIG. 5

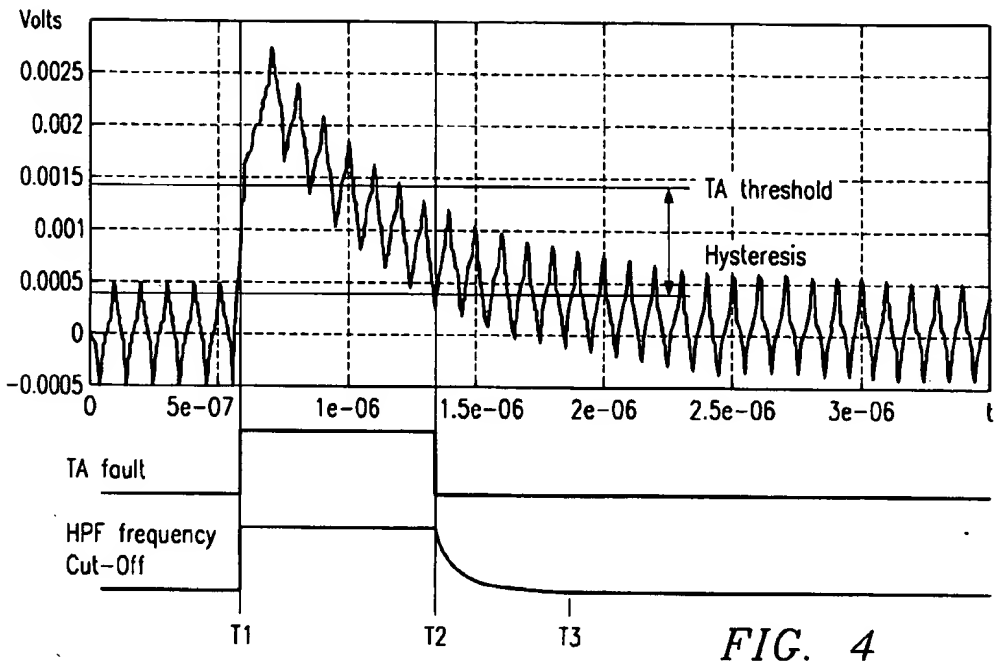

Volts
0.0025
0.002
0.0015
0.001
0.0005
0
-0.0005
0
5e-07
1e-06
1.5e-06
2e-06
2.5e-06
3e-06
t
TA threshold
Hysteresis
TA fault
HPF frequency
Cut-Off
T1
T2
T3

FIG. 4

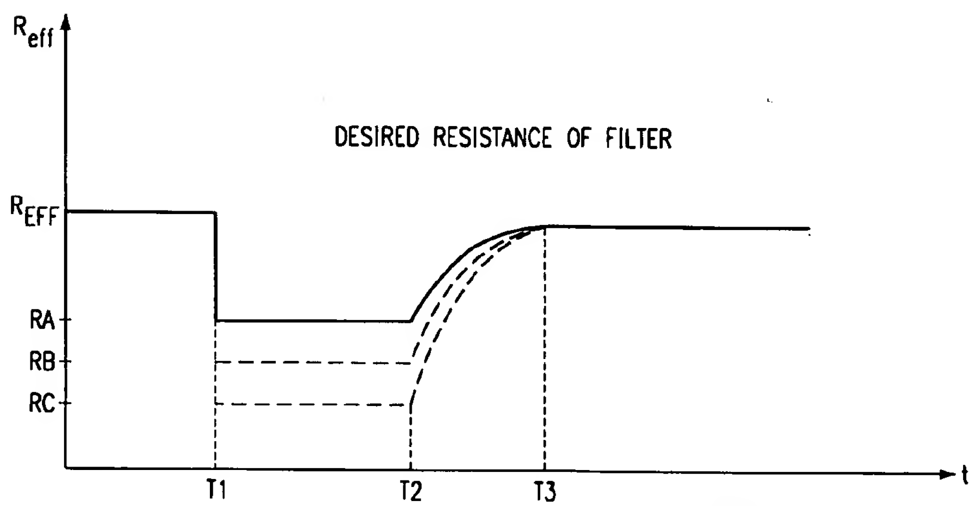

$R_{eff}$
DESIRED RESISTANCE OF FILTER
$R_{EFF}$
RA
RB
RC
T1
T2
T3
t

FIG. 6

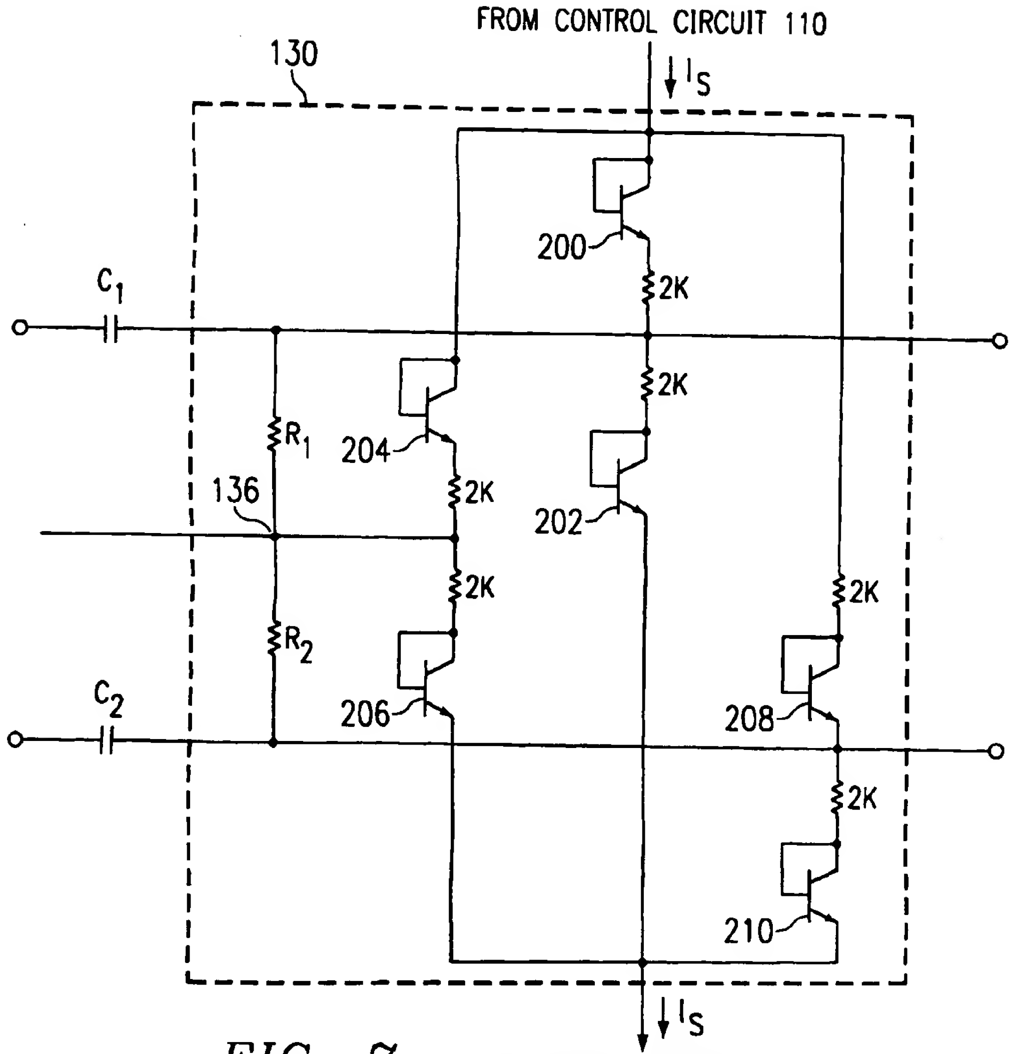

FROM CONTROL CIRCUIT 110
$I_S$
130
200
2K
2K
$C_1$
204
$R_1$
202
136
2K
2K
2K
$R_2$
$C_2$
206
208
2K
210
$I_S$
TO CONTROL CIRCUIT 110

FIG. 7

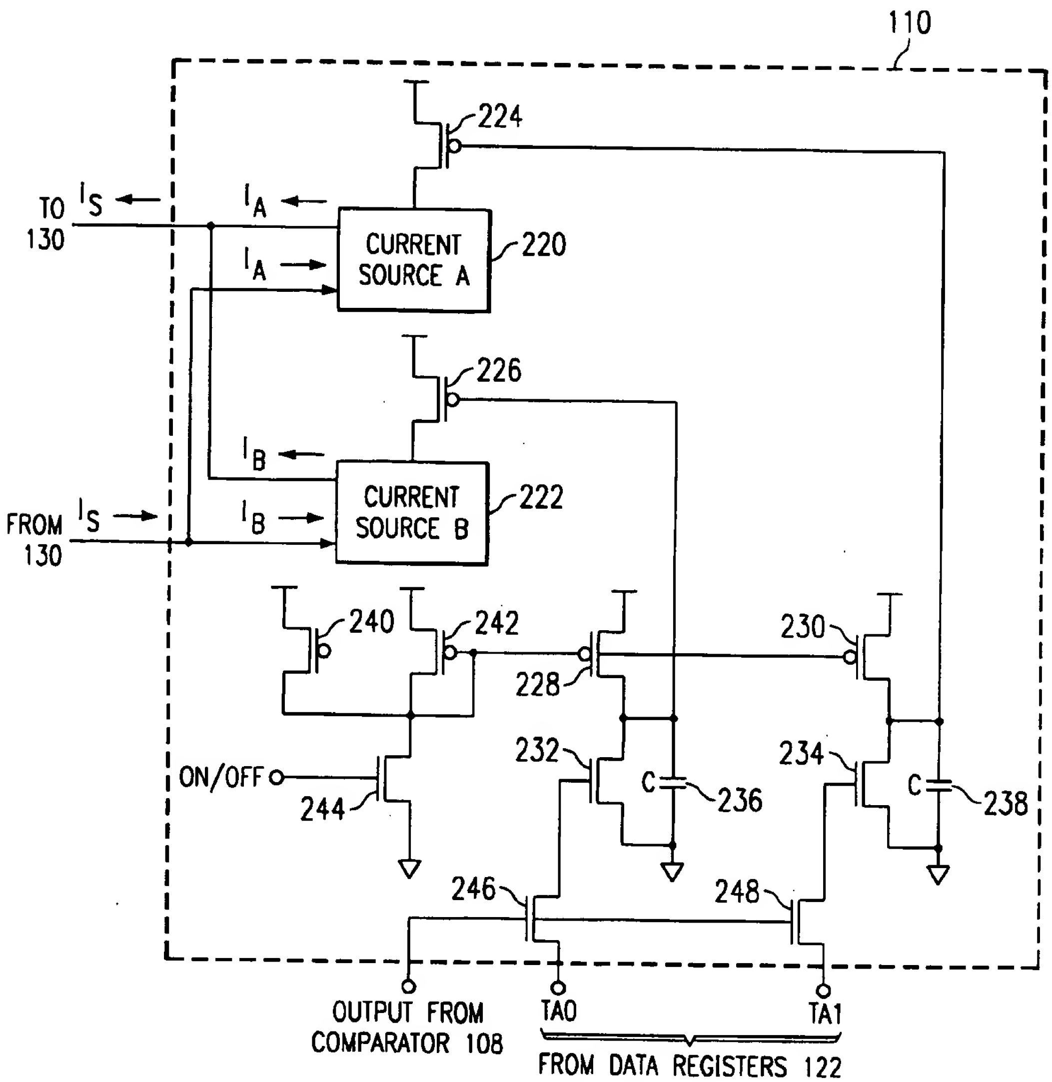

110
224
TO 130
$I_S$
$I_A$
$I_A$
CURRENT SOURCE A
220
226
$I_B$
CURRENT SOURCE B
222
FROM 130
$I_S$
$I_B$
240
242
228
230
232
234
ON/OFF
244
C
236
C
238
246
248
OUTPUT FROM COMPARATOR 108
TA0
TA1
FROM DATA REGISTERS 122

FIG. 8

# APPARATUS AND METHOD FOR REDUCING THERMAL INTERFERENCE IN MR HEADS IN DISK DRIVES

## TECHNICAL FIELD

The present invention relates to disk drives and, in particular, to an apparatus and method for reducing thermal interference (thermal asperity) in magneto-resistive heads in disk drives.

## BACKGROUND

Magneto-resistive and giant (G) magneto-resistive (collectively, MR) heads used in hard disk drive applications utilize a resistive sensing element to read magneticly stored data from a storage disk. The MR heads are thermally sensitive and the resistance of a MR head changes with temperature. The resistance of a typical MR head is given by the equation $R=R_0(1+\beta(T-298))$, where $R_0$ equals about 50 ohms, $\beta$ is the thermal coefficient of the head, and T is temperature in Kelvin. Accordingly, any variations in temperature increase/decrease the resistance of the MR head and affect the readback signal generated by the MR head as it reads data from the disk.

During operation of a disk drive, thermal interference occurs. A thermal interference event is also referred to as a thermal asperity. For additional description and discussion of thermal interference or thermal asperities, reference is made to a published article entitled "Electronic Abatement of Thermal Interference in (G)MR Head Output Signals", *IEEE Transactions on Magnetics*, Vol. 33, No. 5, September 1997 by Klaassen, et al., and is incorporated herein by reference. One solution proposed therein is to increase the low-frequency cutoff of a high pass filter, by switching in a resistor to lower the effective resistance of the RC high-pass filter—thereby increasing the cutoff frequency, when a thermal asperity is detected (the high pass filter is typically used to filter out low frequency signals in the read signal from the MR head). A significant problem with this solution is caused by the switching out of the resistor after the thermal asperity event has subsided to a certain level. This creates ringing and an unwanted offset in the read signal which may cause the loss of data. In addition, there is no control over the value of the resistor (or accuracy of the resistance value) that is switched into the circuit to lower the effective resistance of the high pass filter.

Accordingly, there exists a need for a thermal asperity recovery circuit and method that eliminates or reduces ringing and any unwanted offset in the read signal of a disk drive. In addition, there is a need for an apparatus and method that uses a programmable or variable cutoff frequency in a high pass filter used in thermal asperity recovery.

## SUMMARY OF THE INVENTION

According to the present invention, there is provided a thermal event recovery circuit for filtering a read signal from a read head in a disk drive. The circuit includes a detection circuit for detecting a thermal event that affects the read signal and a filter. The filter includes a variable resistance circuit having a resistance that varies in response to a control input. The resistance is equal to a first predetermined resistance in response to a first control input and equal to a second predetermined resistance in response to a second control input, and the second control input is generated in response to the detection of the thermal event. In another embodiment, there is provided a disk drive having a storage medium, a read head for detecting data on the storage medium and generating a read signal, and the thermal event recovery circuit described above.

In another embodiment of the present invention, there is provided a thermal event recovery circuit for filtering a read signal from a read head in a disk drive. The circuit includes a detection circuit for detecting a thermal event that affects the read signal and a filter. The filter has a first predetermined transfer function in response to a first input and a second predetermined transfer function in response to a second input, and the second input is generated in response to the detection of the thermal event.

In yet another embodiment of the present invention, there is provided a circuit for detecting thermal interference and filtering a read signal from a read head in a disk drive. The circuit includes a detection circuit for detecting thermal interference affecting the read signal, a current source for outputting a first current or second current, and a filter. The filter includes a fixed resistive element for generating a first resistance and a variable resistance circuit for generating a second resistance. The second resistance varies in response to the output of the current source, and the second resistance is equal to a first predetermined resistance in response to the first current and is equal to a second predetermined resistance in response to the second current. The second current is generated in response to the detection of the thermal interference.

In accordance with the present invention, there is also provided a method of reducing the affects of a thermal asperity on a read signal in a disk drive. A read signal is filtered with a filter having a first transfer function. When a thermal interference is detected in the read signal, the first transfer function of the filter is changed to a second transfer function. The read signal is filtered with the filter having the second transfer function. After a predetermined time period has elapsed after the detection of the thermal interference, the second transfer function of the filter is transitioned to the first transfer function.

The foregoing has outlined rather broadly the features and technical advantages of the present invention in order that the detailed description of the invention that follows may be better understood. Additional features and advantages of the invention will be described hereinafter which form the subject of the claims of the invention. It should be appreciated by those skilled in the art that the conception and specific embodiment disclosed may be readily utilized as a basis for modifying or designing other structures for carrying out the same purposes of the present invention. It should also be realized by those skilled in the art that such equivalent constructions do not depart from the spirit and scope of the invention as set forth in the appended claims.

## BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention, and the advantages thereof, reference is made to the following description taken in conjunction with the accompanying drawings, wherein:

FIG. 1 is a block diagram of a computer system and a disk drive utilizing the present invention;

FIGS. 2A–2B are graphs illustrating an output signal from an MR head and the resistance value of the MR head before, during, and after a thermal asperity (heating event) occurs;

FIG. 3 is a block diagram of the read/write head and the pre-amplifier circuit shown in FIG. 1 including a filter (and additional elements) of the present invention;

FIG. 4 illustrates a read signal with a thermal asperity and corresponding TA fault signal and cut-off frequency change for the filter;

FIG. 5 is a more detailed diagram of the filter of the present invention;

FIG. 6 is a graphical representation of the desired effective resistance $R_{eff}$ of the filter of the present invention;

FIG. 7 is a detailed schematic diagram of the programmable resistive element or circuit shown in FIG. 5; and

FIG. 8 is a schematic and block diagram illustrating the control circuit shown in FIG. 3 in accordance with the present invention.

## DETAILED DESCRIPTION OF THE INVENTION

With reference to the drawings, like reference characters designate like or similar elements throughout the drawings.

Now referring to FIG. 1, there is shown a block diagram of a disk drive system **10** including a disk drive **11** in accordance with the present invention. The disk drive **11** includes a storage medium in the form of one or more disks **12**, each of which may contain data on both sides of the disk **12**. Data is stored on the disks **12** and/or read from the disks **12** by one or more read/write heads **14**. The read/write head **14** is an MR head. The read/write head **14** is connected to an arm **16**, with both positionally controlled by a Voice-Coil Motor ("VCM") **18** and a position system **20**. The position system **20**, through the VCM **18**, positionally maintains/moves the head **14** radially over the desired data on the disks **12**. As a signal (or signals) is input to the VCM **18**, the VCM **18** moves the arm **16**, thereby moving the read/write head **14**).

A read channel **22**, including a pre-amplifier circuit **23**, detects data in analog signal form from the head **14** (the head **14** detects generates a read signal from the information stored on the disk **12**) and converts the data into digital form. A controller **24** recognizes and organizes the digital data from the read channel **22** into bytes of data. An interface adapter **26** provides an interface between the controller **24** to a system bus **28** specific to the system used. Typical system buses include ISA, PCI, S-Bus, Nu-Bus, etc. The host system will also typically have other devices, such as a random access memory ("RAM") **30** and a central processing unit ("CPU") **32** attached to the bus **28**. A spindle motor ("SPM") **34** and a SPM control circuit **36** rotates the disk **12** and maintains the disk **12** at the proper speed.

Thermal events occurring during the reading of data from the disk **12** cause large perturbations in the read signal resulting in the loss of data. When the perturbations are relatively short in duration, utilization of error correction coding (ECC) techniques allow for the recovery of the lost data. However, when these events last for a significant period of time, ECC cannot recover the lost data. Sometimes, a re-read of the data sector can recover the data resulting in an increase in the read time. Other times, the thermal event occurs due to the disk surface at that location, which cannot be corrected by a re-read.

Now referring to FIGS. **2A** and **2B**, there are shown two graphs illustrating the output signal from an MR head and the resistance value of the MR head before, during, and after a thermal asperity (heating event) occurs. As shown, the MR head is operating under normal conditions until a time T1 when a thermal asperity (heating event) occurs. At the time T1, the resistance of the MR read head increases, as shown. The read signal increases similarly, as shown. As the thermal asperity slowly decays and the temperature of the MR head returns to normal (or ambient), the resistance and the read signal change also, as shown in FIGS. **2A** and **2B**. A time period t shown in FIG. **2A** illustrates the decay time period for the thermal asperity, after which the data of the read signal is once again accurately read by the read channel.

The time for decay of the read signal back to normal after a thermal asperity occurs depends on several factors, including the size or magnitude of the event causing the thermal asperity, the magnitude of the temperature increase, the ambient temperature, cooling effects of the surrounding environment, etc. As will be appreciated, thermal events occurring in disk drives may be of any length and/or magnitude. Further, the thermal event may also be a cooling event, where the resistance of the MR head decreases.

It is not common for the decay of the read signal back to normal to take up to about one microsecond (and even larger, up to 2–3 microseconds). During this time period, data on the read signal may be lost. At typical data bit rates for current hard drives of about 200 Mbit/sec, about 200 bits or about 25 bytes of data (burst) may be lost due to a thermal asperity. Under typical industry standards, error correction may allow for recovery of a lost data burst of up to about 5 bytes in length, depending on the ECC techniques used. Thermal asperities are a major problem at present, and increases in data read rates further exacerbates the problem.

Now referring to FIG. **3**, there is shown a block diagram the read/write head **14** and the pre-amplifier circuit **23** in accordance with the present invention. The read signal from the head **14** is input to an amplifier **100** of the pre-amplifier circuit **23**. A thermal asperity recovery circuit **102** receives the read signal and outputs the read signal to a differential amplifier **104**. The thermal asperity recovery circuit **102** includes a filter **112** and a control circuit **110** for controlling the transfer characteristics (or transfer function) of the filter **112**. The output of the differential amplifier **104** is input to the read channel circuitry (not shown) and input to a thermal asperity detector **106** having a differential comparator **108**. When a thermal asperity is detected, a signal is generated by the detector **106** and output to the control circuit **110** for controlling the filter **114**.

In general operation, the thermal asperity detector **106** monitors the read signal coming from the head **14**. When there is a variation of the read signal voltage above (or below, when a cooling event occurs) a predetermined threshold, the differential comparator **108** is triggered indicating a thermal asperity is detected (sometimes called a TA fault). As will be appreciated, the read signal may be a single-ended signal, and the invention described herein can be modified by those skilled in the art to operate with a single-ended signal, however, differential signals are preferred. The output of the comparator **108** is not latched, allowing a TA length monitoring circuit (not shown) to monitor the length of the thermal asperity. The predetermined threshold voltage of the comparator **108** is preferably generated by a 6-bit digital-to-analog converter (DAC)(not shown) and data registers **122**, including a 6-bit data register for generating the 6-bit input to the DAC. In the preferred embodiment, the 6-bit DAC provides an output voltage generally in the range of 0 to 0.8 volts. The data registers **122** are programmed through an interface **120** (serial or parallel).

The programmability of the comparator threshold provides flexibility in selecting a threshold below (or above) which a thermal asperity having a given magnitude will not generally cause data loss (i.e., those that do not pose a problem and can be corrected by ECC, thus no detection is

necessary). Additional data register bits may be used to enable/disable the detector **106** and for TA fault reporting.

The comparator **106** includes a hysteresis function, as illustrated in FIG. **4**. As shown at T1, a thermal asperity (heating event shown) occurs and the read signal increases in amplitude and slowly returns to normal as the temperature of the MR head returns to normal (or ambient), as shown in FIG. **4**. When the amplitude of the read signal rises above the TA threshold (the threshold of the comparator **108**), a TA fault is detected and the control circuit **110** activates the thermal asperity recovery circuit **102** and the cutoff frequency (or transfer function) of the filter **114** therein (shown in FIG. **3**) is increased from an initial cutoff frequency to a predetermined higher cutoff frequency, illustrated conceptually in FIG. **4**.

As the thermal asperity slowly subsides, at a time T2, the amplitude of the read signal falls below a hysteresis threshold of the comparator **106**. At this time, the TA fault is no longer detected and the thermal asperity recovery circuit **102** is deactivated Deactivation results in the cutoff frequency of the filter transitioning to its initial cutoff frequency, identified at point T3This transition (from T2 to T3) may take any form, however, including any one of the three following forms: (1) almost instantly (depending only on the physical limitations of the circuits utilized), (2) linearly (first order, i.e., substantially constant slope) over a period of time, or (3) nonlinearly (i.e., second order or higher, substantially non-constant slope, similar to the charging/discharging curve of a capacitor) over a period of time.

If the transition from the higher cutoff frequency to the initial cutoff frequency occurs abruptly, similar to the abrupt transition from the initial cutoff frequency to the higher cutoff frequency, an offset is generated in the read signal which is generally unwanted and may cause read channel data detection problems. However, in a preferable embodiment of the present invention, the transition (linearly or nonlinearly) from the higher cutoff frequency to the initial cutoff frequency occurs relatively slowly (over a period of time), unlike the abrupt transition from the initial cutoff frequency to the higher cutoff frequency. This reduces or eliminates the offset problem. Most preferred, the transition is nonlinear. The time period for this transition can range anywhere from about 50 nanoseconds to about 1 microsecond, and even longer, and preferably is between about 200 nanoseconds and 700 nanoseconds. The circuitry and method of generating/performing the transition is described below.

Now referring to FIG. **5**, there is illustrated in more detail the filter **112** of the thermal asperity recovery circuit **102**. The filter **112** includes a capacitor **C1**, a capacitor **C2**, and a programmable resistive element **130** including a resistor **R1**, a resistor **R2** and a variable resistance circuit **132**. The capacitors **C1** and **C2** and the resistive element **130** provide an RC-type high pass filter for the differential read signal output from the amplifier **100**. As will be appreciated, a single-ended read signal could be optionally used, and the RC-type filter would be a single-ended filter. However, differential signals are preferred. It will be understood that filters other than an RC-type filter may be used for the filter **112** (including second order and higher function filters), as long as the cut-off frequency varies with a change in resistance, but the preferred filter **112** is an RC-type high pass filter.

The resistors **R1** and **R2** are substantially fixed resistance resistors, and may include other devices that provide a resistance, such as transistors. In the preferred embodiment,



the resistors **R1** and **R2** have a value of 200 Kohms and are provided by MOSFETs (not shown). A bias circuit **134** provides a voltage reference or voltage bias to the filter **112** (thereby biasing the MOSFETs used for the resistors **R1** and **R2**), as shown in FIG. **5**.

The variable resistance circuit **132** is coupled in parallel with the resistors **R1** and **R2** and provides a variable resistance. The variable resistance is programmable based on inputs from the control circuit **110**. Characteristics of the RC filter are better understood with reference to a basic RC filter, therefore, the description shall utilize the capacitor C1, the resistor **R1** and the programmable resistance obtained from the variable resistance circuit **132**.

The resistor **R1** and the programmed resistance of the variable resistance circuit **132** provides an effective resistance $R_{eff}$. The value of the capacitor **C1** and the effective resistance $R_{eff}$ determines the cut-off frequency of the high pass RC filter. In the present invention, resistor **R1** and the capacitor **C1** are substantially fixed, therefore, as the resistance of the variable resistance circuit **132** varies, so does the cut-off frequency of the filter **112**.

Now referring to FIG. **6**, there is shown a graphical representation of the desired effective resistance $R_{eff}$ of the filter **112** of the thermal asperity recovery circuit **102**. During normal operation of the read channel (i.e., no detected thermal interference), the effective resistance $R_{eff}$ is relatively constant at $R_{EFF}$, as shown. In the preferred embodiment, during this period of time, the resistance of the variable resistance circuit **132** is a relatively high impedance (coupled in parallel with the resistor R1), resulting in the effective resistance $R_{eff}$ of the filter **112** substantially equaling the resistance of the resistor **R1** ($R_{EFF}$).

When a thermal asperity is detected at the time T1, the effective resistance $R_{eff}$ of the filter **112** is lowered, thus raising the cut-off frequency of the filter **112**. The effective resistance $R_{eff}$ is lowered by programming the variable resistance circuit **132** to a predetermined resistance in response to an input signal from the control circuit **110**. For example, if the variable resistance circuit **132** is programmed to a value of 200 Kohms, the effective resistance $R_{eff}$ will be 100 Kohms (R1 in parallel with variable resistance=200K in parallel with 200K=100K).

In the preferred embodiment, the variable resistance circuit **132** has four programmable resistance settings, with each setting resulting in one of four ($R_{EFF}$, RA, RB, RC) different effective resistances $R_{eff}$ for the filter **112**, and thus a different cut-off frequency. However, any number of programmed resistances may be used. As will be appreciated, the programmed resistances of the variable resistance circuit **132** are selected to achieve the cut-off frequency(s) desired for the filter **112**. The programmable thermal asperity recovery circuit **132** of the present invention provides flexibility thereby allowing utilization in read channels having potentially different or varying characteristics (e.g., different data rates, different causes for the thermal interference, etc.).

At the time T2, and as described earlier, the TA fault is no longer detected and the thermal asperity recovery circuit **102** is deactivated. Upon deactivation, the cutoff frequency of the filter transitions to its initial cutoff frequency, identified at point T3. In the preferred embodiment, the deactivation is accomplished by switching in the high impedance (or open circuit) in parallel with the resistor **R1**, that is present in normal operation (no thermal asperity detected).

Now referring to FIG. **7**, there is illustrated a detailed schematic diagram of the programmable resistive element or

circuit **130** including the previously described resistors R1 and R2 and the variable resistance circuit **132**. The resistance of the resistive element **130** is programmable in response to the magnitude of an input signal from the control circuit **110**. In the preferred embodiment, a current $I_s$ controls the resistance of the variable resistance circuit **132**, which in turn varies the resistance of the resistive element **130** of the filter **112**.

The variable resistance circuit **132** includes a combination of transistors **200, 202, 204, 206, 208, 210** and resistors (six 2K ohm resistors) interconnected, as shown in FIG. **7**, in a configuration resulting in a resistive element coupled in parallel with the fixed resistors R1 and R2. The resistance of the variable resistance circuit **132** depends on the magnitude of the current flowing through the transistors **200, 202, 204, 206, 208, 210**. The transistors **200, 202, 204, 206, 208, 210** each act as a resistive element when current flows through them, with the resistance value depending on the magnitude of the current flow therethrough and device characteristics. When the current $I_s$ is essentially zero, the resistance of the transistors is high (high impedance) resulting in a resistance of the filter **112** substantially equal to the value of fixed resistors R1 and R2. In the preferred embodiment, the transistors **200, 202, 204, 206, 208, 210** are bipolar transistors. It will be understood by those skilled in the art that the characteristics of the transistors should be selected based on several factors, including the desired resistance(s) of the variable resistance circuit **132** (and ultimately the resistance R for the high pass filter **112**) and the magnitude of the current Is that is utilized.

Now referring to FIG. **8**, there is illustrated one embodiment of the control circuit **110** for programming/setting the resistance of the variable resistance circuit **132** (and ultimately programming/setting the cut-off frequency/transfer function of the filter **112**). The control circuit **110** includes a first current source (A) **220** and a second current source (B) **222**. The current sources **220** and **222** provide sources of current (or reference current), and output a substantially fixed first current $I_A$ and a substantially fixed second current $I_B$, respectively. These currents are summed together to provide the current $I_s$ input to the resistive element **130** (see FIG. **7**). Accordingly, the current source A **220** and the current source B **222** provide a programmable current source outputting the programmable current $I_s$. In the preferred embodiment, the current $I_s$ equals zero, $I_A$, $I_B$, or $I_A+I_B$. As will be appreciated, additional current sources, such as C, D, E, etc. could be used to increase the programmability.

Operation of the control circuit **110** is enabled/disabled by operation of the transistors **240, 242, 244** and an enable/disable signal. The enable/disable signal may be generated by additional control circuitry (not shown), as desired.

The general on/off operation of the current source A **220** is controlled by transistors **224, 230, 234**, and a signal **TA1** output from the data registers **122**, as shown. When the signal TA1 equals a logic one, the current source A **220** is turned off and no current is output. When the signal TA1 equals a logic zero, the current source A **220** is turned on and outputs current $I_A$. Similarly, the general on/off operation of the current source B **222** is controlled by transistors **226, 232, 236**, and a signal **TA0** output from the data registers **122**, as shown. When the signal **TA0** equals a logic one, the current source B **222** is turned off and no current is output. When the signal **TA0** equals a logic zero, the current source B **222** is turned on and outputs current $I_B$. Two transistors **246, 248** provide an enable/disable function based upon the detection of a thermal asperity output from the comparator **108**. As will be appreciated, this function may be integrated with the output of the TA registers producing the signals **TA0** and **TA1**.

In the preferred embodiment, the current $I_s$=0, when no thermal asperity is detected by the comparator **108**, or when TA1=logic zero and **TA0**=logic zero. The current $I_s$=$I_B$, when TA1=logic zero and **TA0**=logic one. The current $I_s$=$I_A$, when TA1=logic one and TA0=logic zero. The current $I_s$=$I_B$+$I_A$, when TA1=logic one and **TA0**=logic one. Also, in the preferred embodiment, the current source A **220** outputs **20** microamperes and the current source B **222** outputs **10** microamperes. Therefore, the current Is is programmable to four levels: zero, 10, 20 or 30 microamps.

Because the resistive value of the transistors **200, 202, 204, 206, 208, 210** varies with the amount of current flowing therethrough, the resistance of the variable resistance circuit **132**, and hence the cut-off frequency (transfer function) of the high pass filter **112**, varies and is programmable in response to the programmable current source (current sources **220, 222**). Accordingly, for different values of current $I_s$, the cut-off frequency (transfer function) of the filter **112** is different.

In the preferred embodiment, and under current industry specifications, the initial cutoff frequency (under normal operating conditions when no thermal asperity is detected) is around 500 KHz, and the cutoff frequency is programmable in the range between 500 KHz and 20 MHz. As data rates go higher, the programmable cut-off frequencies may also need to go higher. It will be understood that the factors influencing the desired cut-off frequency (based on the value of resistance) of the filter **112** include the programmable values of the current $I_s$, the number, type and configuration of elements making up the variable resistance circuit **132**, as well as the resistance characteristics of transistors **200, 202, 204, 206, 208, 210**.

The resistance $R_e$ for a typical bipolar transistor is given by the equation $R_e=(V_T/I_E)$ where $V_T$ is typically 25 mV, and this resistance is relatively linear. For example, currents of 1, 10, 100, and 1000 microamps generate resistance values of about 25 Kohms, 2.5 Kohms, 250 ohms, and 25 ohms, respectively. Accordingly, a person of ordinary skill in the art can obtain desired resistance values for the variable resistance circuit 132 and achieve the filter cut-off frequency as desired.

Now referring back to FIGS. **4** and **6**, the realization of the transition of the cut-off frequency (FIG. **4**) and the resistance of the filter (FIG. **6**) between time T2 and T3 will now be explained. Referring to FIG. **8**, the general on/off operation of the current sources **220, 222** was explained above. Additional circuitry is added to achieve the slower transition, as described earlier herein, from the programmed cut-off frequency (transfer function) to the initial cut-off frequency (or from the programmed resistance to the initial resistance). The additional circuitry is in the form of a capacitor **236** coupled to ground and to the S/D of the transistor **232** and a capacitor coupled to ground and coupled to the S/D of the transistor **234**. The capacitors **238, 236** are utilized to slowly turn off the p-channel transistors **224, 226** coupling power to the current sources **220, 222**, respectively.

Assuming a thermal asperity is detected and the current sources **220, 222** are turned on, when the thermal asperity is no longer detected, the signals at the gates of the transistors **232, 234** are logic zero (or floating), thereby turning off the transistors **232, 234**. The transistors **228, 230** then provide a current to charge the capacitors **236, 238**, respectively, to a logic one, thus slowly turning off the current sources **220, 222**. Without the capacitors **236, 238**, the signal at the gates of the transistors **224, 226** would rise abruptly to a logic one, thereby quickly shutting off the current sources **220, 222**.

Different values for the capacitors **236**, **238** (as well as additional circuitry, for example, resistors, like resistors) may be used to shape the transition (change in resistance of the filter **112** and change in cut-off frequency (transfer function)) between the time T2 and T3, as desired. In the preferred embodiment, the capacitors **236**, **238** have a value of about two picofarads. The transition as described helps eliminate or reduce unwanted offset and ringing problems.

The general operation of the present invention will now be described. Under normal operating conditions, i.e., when no thermal asperity is detected (a thermal asperity may be present but undetected or not relevant because of its magnitude/size), the filter **114** provides a high pass filtering function operating at a first cut-off frequency (transfer function) for the readback signal from the read head **14**. The first cut-off frequency is determined by setting or programming the resistive element in the filter **114** to have a predetermined resistance value. The amount of resistance is set or programmed in response to a first input to a programmable current source. The first input initiates a first predetermined amount of current from the programmable current source and the resistance is dependent on the magnitude of the current flowing.

Upon detection of a relevant thermal asperity upon exceeding a predetermined threshold, a second input causes the programmable current source to output a different, predetermined amount of current. This changes the value of the resistance in the filter **114** and results in a different, second cut-off frequency (transfer function) for the filter **114**. The filter **114** has been programmed to have a different transfer function which is utilized to eliminate or reduce the effects of the thermal asperity by filtering the readback signal. In response to thermal interference detection, the filter **114** provides a high pass filtering function operating at a second first cut-off frequency (transfer function) for the readback signal from the read head **14**. In the preferred embodiment, the second cut-off frequency is higher than the first cut-off frequency of the filter **114**.

Different amounts of current are programmable based on different inputs to the programmable current source. Therefore, the cut-off frequency of the filter **114** can be set or programmed to have one of a multitude of possible cut-off frequencies.

When the magnitude of the relevant thermal asperity decreases and the read signal transitions back across the predetermined threshold (TA fault no longer detected), the current source is programmed to the first amount of current thereby programming the cut-off frequency (transfer function) of the filter **114** back to first cut-off frequency. The filter **114** then again provides a high pass filtering function operating at the first cut-off frequency (transfer function) for the readback signal from the read head **14**.

Another feature of the present invention operates to slowly (relatively slowly) transition the cut-off frequency (transfer function) of the filter **114** from the second cut-off frequency back to the first cut-off frequency (by slowly transitioning the resistance of the variable resistance circuit **132**), see FIGS. **4** and **6**. Circuitry is utilized to create a relatively slow and predictable control signal (voltage) to the programmable current source to slowly change the amount of current output therefrom. In the preferred embodiment, a capacitor provides this function.

Although the present invention and its advantages have been described in the foregoing detailed description and illustrated in the accompanying drawings, it will be understood by those skilled in the art that the invention is not limited to the embodiment(s) disclosed but is capable of numerous rearrangements, substitutions and modifications without departing from the spirit and scope of the invention as defined by the appended claims.



What is claimed is:

1. A thermal event recovery circuit for filtering a read signal from a read head in a disk drive, the circuit comprising:

a detection circuit for detecting a thermal event affecting the read signal; and

a filter comprising a variable resistance circuit having a resistance that varies in response to a control input, the resistance equal to a first predetermined resistance in response to a first control input and equal to a second predetermined resistance in response to a second control input, the second control input generated in response to the detection of the thermal, event and wherein the first control input comprises a first current and the second control input comprises a second current.

2. The circuit in accordance with claim **1** wherein the filter is a high-pass filter and the filter comprises a capacitive element and the variable resistance circuit comprises a fixed resistance element and a variable resistance element coupled in parallel with the fixed resistance element.

3. The circuit in accordance with claim **1** wherein the resistance of the variable resistance circuit equals a third predetermined resistance in response to a third control input, and the second control input or the third control input is generated in response to the detection of the thermal event, and wherein the third control input comprises a third current.

4. The circuit in accordance with claim **3** wherein the control input is in the form of a current output from a current source, and the first control input comprises the current having a first magnitude, the second control input comprises the current having a second magnitude, and the third control input comprises the current having a third magnitude.

5. The circuit in accordance with claim **1** further comprising a current source outputting the first current in response to the first control input and outputting the second current in response to the second control input, wherein the first predetermined resistance is generated in response to the first current and the second predetermined resistance is generated in response to the second current.

6. The circuit in accordance with claim **5** wherein the resistance of the variable resistance circuit equals a third predetermined resistance in response to a third control input, the current source outputs a third current in response to the third control input and the third predetermined resistance is generated in response to the third current, and the second control input or the third control input is generated in response to the detection of the thermal event.

7. The circuit in accordance with claim **1** wherein the first and second predetermined resistances are controlled using a current.

8. The circuit in accordance with claim **1** wherein the resistance of the variable resistance circuit slowly transitions during a transition period from the second predetermined resistance to the first predetermined resistance after the thermal event is no longer detected.

9. The circuit in accordance with claim **8** wherein the transition period is greater than about 50 nanoseconds.

10. The circuit in accordance with claim **8** wherein the transition follows a transition curve and the transition period is greater than about 50 nanoseconds.

11. The circuit in accordance with claim **10** wherein the transition curve is nonlinear.

12. The circuit in accordance with claim 1 further comprising transition circuitry for transitioning during a transition period the resistance of the variable resistance circuit from the first predetermined resistance to the second predetermined resistance after the thermal event is no longer detected.

13. A thermal event recovery circuit for filtering a read signal from a read head in a disk drive, the circuit comprising:

a detection circuit for detecting a thermal event affecting the read signal; and

a filter having a first predetermined transfer function in response to a first input, and having a second predetermined transfer function in response to a second input, the second input generated in response to the detection of the thermal event, and wherein the first input comprises a first current and the second input comprises a second current.

14. The circuit in accordance with claim 13 wherein the filter is a high-pass filter and the filter comprises a capacitive element and a resistive element, the resistive element comprising a fixed resistance element and a variable resistance circuit coupled in parallel with the fixed resistance element.

15. The circuit in accordance with claim 13 wherein the filter has a third predetermined transfer function in response to a third input, and the second input or the third input is generated in response to the detection of the thermal event, and wherein the third input comprises a third current.

16. The circuit in accordance with claim 13 wherein the transfer function of the filter slowly transitions during a transition period from the second transfer function to the first transfer function after the thermal event is no longer detected.

17. The circuit in accordance with claim 16 wherein the transition period is greater than about 50 nanoseconds.

18. A circuit for detecting thermal interference and filtering a read signal from a read head in a disk drive, the circuit comprising:

a detection circuit for detecting thermal interference affecting the read signal;

a current source for outputting a first current or second current; and

a filter comprising,

a fixed resistive element generating a first resistance, and

a variable resistance circuit generating a second resistance that varies in response to the output of the current source, the second resistance equal to a first predetermined resistance in response to the first current and equal to a second predetermined resistance in response to the second current, the second current generated in response to the detection of the thermal interference.

19. The circuit in accordance with claim 18 wherein the current source outputs a third current and the second resistance equals a third predetermined resistance in response to the third current, the second current or the third current generated in response to the detection of the thermal event.

20. The circuit in accordance with claim 18 wherein the second resistance of the variable resistance circuit slowly transitions during a transition period from the second predetermined resistance to the first predetermined resistance after the thermal event is no longer detected.

21. The circuit in accordance with claim 20 wherein the transition period is greater than about 50 nanoseconds.

22. A disk drive comprising:

a storage medium,

a read head for detecting data on the storage medium and generating a read signal;

a detection circuit for detecting a thermal event affecting the read signal; and

a filter comprising a variable resistance circuit having a resistance that varies in response to a control input, the resistance equal to a first predetermined resistance in response to a first control input and equal to a second predetermined resistance in response to a second control input, the second control input generated in response to the detection of the thermal event, and wherein the first control input comprises a first current and the second control input comprises a second current.

23. The circuit in accordance with claim 22 wherein the filter is a high-pass filter and the filter comprises a capacitive element and the variable resistance circuit comprises a fixed resistance element and a variable resistance element coupled in parallel with the fixed resistance element.

24. The circuit in accordance with claim 22 wherein the resistance of the variable resistance circuit equals a third predetermined resistance in response to a third control input, and the second control input or the third control input is generated in response to the detection of the thermal event, and wherein the third control input comprises a third current.

25. The circuit in accordance with claim 22 further comprising a current source outputting the first current in response to the first control input and outputting the second current in response to the second control input, wherein the first predetermined resistance is generated in response to the first current and the second predetermined resistance is generated in response to the second current.

26. The circuit in accordance with claim 22 wherein the resistance of the variable resistance circuit slowly transitions during a transition period from the second predetermined resistance to the first predetermined resistance after the thermal event is no longer detected.

27. A method of reducing the affects of a thermal asperity on a read signal in a disk drive, comprising the steps of:

filtering the read signal with a filter having a first transfer function;

detecting thermal interference in the read signal;

changing, in response to the detection of the thermal interference, the first transfer function of the filter to a second transfer function, the first transfer function dependent upon a first predetermined resistance of the filter and the second transfer function dependent upon a second predetermined resistance of the filter, and whereby the first predetermined resistance is generated in response to a first current and the second predetermined resistance is generated in response to a second current;

filtering the signal with the filter having the second transfer function; and

transitioning, after a predetermined time period has elapsed after the detection of the thermal interference, the second transfer function of the filter to the first transfer function.

28. The method in accordance with claim 27 wherein the first transfer function comprises substantially a high pass transfer function having a first cut-off frequency and the second transfer function comprises substantially a high pass transfer function having a second cut-off frequency.

29. The method in accordance with claim 27 further comprising the step of selecting one of a plurality of transfer functions as the second transfer function.

30. The method in accordance with claim 27 wherein the step of transitioning the second transfer function of the filter

to the first transfer function occurs over a transition period greater than about 50 nanoseconds.

31. A thermal event recovery circuit for filtering a read signal from a read head in a disk drive, the circuit comprising:

a detection circuit for detecting a thermal event affecting the read signal; and

a filter comprising a variable resistance circuit having a resistance that varies in response to a control input, the resistance equal to a first predetermined resistance in response to a first control input and equal to a second predetermined resistance in response to a second control input, the second control input generated in response to the detection of the thermal event, and wherein the resistance of the variable resistance circuit equals a third predetermined resistance in response to a third control input, and the second control input or the third control input is generated in response to the detection of the thermal event.

32. A thermal event recovery circuit for filtering a read signal from a read head in a disk drive, the circuit comprising:

a detection circuit for detecting a thermal event affecting the read signal; and

a filter comprising a variable resistance circuit having a resistance that varies in response to a control input, the resistance equal to a first predetermined resistance in response to a first control input and equal to a second predetermined resistance in response to a second control input, the second control input generated in response to the detection of the thermal event, wherein the resistance of the variable resistance circuit slowly transitions during a transition period greater than about 50 nanoseconds from the second predetermined resistance to the first predetermined resistance after the thermal event is no longer detected.

33. A thermal event recovery circuit for filtering a read signal from a read head in a disk drive, the circuit comprising:

a detection circuit for detecting a thermal event affecting the read signal; and

a filter having a first predetermined transfer function in response to a first input, and having a second predetermined transfer function in response to a second input, the second input generated in response to the detection of the thermal event, and wherein the filter has a third predetermined transfer function in response to a third input, and the second input or the third input is generated in response to the detection of the thermal event.

34. A thermal event recovery circuit for filtering a read signal from a read head in a disk drive, the circuit comprising:

a detection circuit for detecting a thermal event affecting the read signal; and

a filter having a first predetermined transfer function in response to a first input, and having a second predetermined transfer function in response to a second input, the second input generated in response to the detection of the thermal event, and wherein the transfer function of the filter slowly transitions during a transition period greater than about 50 nanoseconds from the second transfer function to the first transfer function after the thermal event is no longer detected.

35. A disk drive comprising:

a storage medium,



a read head for detecting data on the storage medium and generating a read signal;

a detection circuit for detecting a thermal event affecting the read signal; and

a filter comprising a variable resistance circuit having a resistance that varies in response to a control input, the resistance equal to a first predetermined resistance in response to a first control input and equal to a second predetermined resistance in response to a second control input, the second control input generated in response to the detection of the thermal event, and wherein the resistance of the variable resistance circuit equals a third predetermined resistance in response to a third control input and the second control input or the third control input is generated in response to the detection of the thermal event.

36. A thermal event recovery circuit for filtering a read signal from a read head in a disk drive, the circuit comprising:

a detection circuit for detecting a thermal event affecting the read signal; and

a filter comprising a variable resistance circuit having a resistance that varies in response to a control signal having a first current state and a second current state, the resistance equal to a first predetermined resistance in response to the first current state and equal to a second predetermined resistance in response to the second current state, the first current state comprising a current having a first magnitude and the second current state comprising a current having a second magnitude.

37. A thermal event recovery circuit for filtering a read signal from a read head in a disk drive, the circuit comprising:

a detection circuit for detecting a thermal event affecting the read signal; and

a filter having a first predetermined transfer function in response to a control signal having a first current state, and having a second predetermined transfer fucntion in response to the control signal having a second current state, the first current state comprising a current having a first magnitude and the second current state comprising a current having a second magnitude.

38. A thermal event recovery circuit for filtering a read signal from a read head in a disk drive, the circuit comprising:

a detection circuit for detecting a thermal event affecting the read signal; and

a filter comprising a variable resistance circuit having a resistance that varies in response to a control input having a first state and a second state, the resistance equal to a first predetermined resistance in response to the first state and equal to a second predetermined resistance in response to the second state, the second state generated in response to the detection of the thermal event, wherein the resistance of the variable resistance circuit slowly transitions during a transition period greater than about 50 nanoseconds from the second predetermined resistance to the first predetermined resistance after the thermal event is no longer detected.

39. A thermal event recovery circuit for filtering a read signal from a read head in a disk drive, the circuit comprising:

a detection circuit for detecting a thermal event affecting the read signal; and

a filter having a first predetermined transfer function in response a control input having a first state, and having

a second predetermined transfer function in response to the control input having a second state, the second state generated in response to the detection of the thermal event, and wherein the transfer function of the filter slowly transitions during a transition period greater than about 50 nanoseconds from the second transfer function to the first transfer function after the thermal event is no longer detected.

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